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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Navy Department

FREE-SPINNING-TUNNEL TESTS OF A $\frac{1}{27}$-SCALE MODEL

OF THE DOUGLAS XF3D-1 AIRPLANE

TED NO. NACA DE 312

By

Stanley H. Scher

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

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SUMMARY

Free—spinning—tunnel tests have been made on a $\frac{1}{27}$ — scale model of the Douglas XF3D—1 airplane to confirm a preliminary evaluation made of the airplane spin and recovery characteristics and previously reported. Recovery characteristics were satisfactory for erect and inverted spins when the model was in the clean condition. When the slow—down brakes were open, recoveries were slow. The pedal force necessary to reverse the airplane rudder during a spin will be within the physical capabilities of the pilot. A 10—foot—diameter parachute attached to the tail of the airplane (laid—out—flat diameter, drag coefficient 0.7) or a 4.5—foot—diameter parachute attached to the outboard wing tip will be satisfactory for emergency·spin recovery from demonstration spins. If it becomes necessary for the crew to abandon the airplane during a spin, they should leave from the outboard side of the cockpit.

The test results indicated spin and recovery characteristics generally similar to those indicated in the preliminary evaluation.

INTRODUCTION

The Bureau of Aeronautics, Navy Department, requested that the National Advisory Committee for Aeronautics make an investigation of the spin and recovery characteristics of the Douglas XF3D—1 airplane, which is a midwing, two—place, jet—propelled fighter airplane. A preliminary evaluation of the spin and recovery characteristics was presented in reference 1 and was based primarily on free—spinning—tunnel tests of an

available model which was modified to closely simulate the XF3D-1 design.
In an attempt to confirm the spin and recovery characteristics indicated
in the preliminary evaluation and to more closely define these charac-
teristics, free-spinning-tunnel tests have now been completed on an
actual $\frac{1}{27}$ - scale model of the XF3D-1 airplane, and the results are pre-
sented herein.

Erect spin tests were made with the model in the normal gross-
weight loading for the clean condition (landing flaps, landing gear, and
slow-down brakes retracted) and with the slow-down brakes fully opened.
Brief inverted spin tests with the model in the clean condition were
also made. Estimates have been made of the rudder-pedal force that
would be encountered in effecting recoveries from spins and of the spin-
recovery-parachute requirements for demonstration spinning. The side of
the cockpit from which the crew should leave if it becomes necessary to
abandon the airplane during a spin is indicated.

SYMBOLS

b   wing span, feet

S   wing area, square feet

$\bar{c}$ mean aerodynamic chord, feet

$x/\bar{c}$ ratio of distance of center of gravity rearward of leading
                   edge of mean aerodynamic chord to mean aerodynamic
                   chord

$z/\bar{c}$ ratio of distance between center of gravity and fuselage
                   reference line to mean aerodynamic chord (positive when
                   center of gravity is below fuselage reference line)

m   mass of airplane, slugs

I_X, I_Y, I_Z moments of inertia about X-, Y-, and Z-body axes, respec-
                   tively, slug-feet^2

$\dfrac{I_X - I_Y}{mb^2}$ inertia yawing-moment parameter

$\dfrac{I_Y - I_Z}{mb^2}$ inertia rolling-moment parameter

$\dfrac{I_Z - I_X}{mb^2}$ inertia pitching-moment parameter

ρ air density, slugs per cubic foot

μ relative density of airplane $\left(\dfrac{m}{\rho Sb}\right)$

α angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), degrees

ϕ angle between span axis and horizontal, degrees

V full-scale true rate of descent, feet per second

Ω full-scale angular velocity about spin axis, revolutions per second

APPARATUS AND METHODS

Model

A $\dfrac{1}{27}$-scale model of the XF3D-1 airplane was furnished by the Bureau of Aeronautics, Navy Department and was checked for dimensional accuracy and prepared for testing at the Langley Laboratory. Photographs of the model in the clean condition and with the slow-down brakes opened are shown as figures 1 and 2, respectively. A three-view drawing of the model is shown as figure 3, and the dimensional characteristics of the XF3D-1 airplane represented by the model are presented in table I. The model was ballasted with lead weights to obtain dynamic similarity to the XF3D-1 airplane at an altitude of 16,000 feet ($\rho = 0.001448$ slug/cu ft). A remote-control mechanism was installed in the model to actuate the rudder for recovery tests.

Wind Tunnel and Testing Technique

The tests were performed in the Langley 20-foot free-spinning tunnel, the operation of which is generally similar to that described in reference 2 for the Langley 15-foot free-spinning tunnel except that the model-launching technique has been changed. With the controls set in the desired position, the model is launched by hand with rotation into the vertically rising air stream. A photograph which shows the test section of the Langley 20-foot free-spinning tunnel and a model spinning in the tunnel is shown as figure 4. After a number of turns in the established

spin, the recovery attempt is made by moving one or more controls by
means of the remote-control mechanism. After recovery, the model dives
into a safety net. The spin data obtained from these tests are then
converted to corresponding full-scale values by methods described in
reference 2.

In accordance with standard spin-tunnel procedure, tests were per-
formed to determine the spin and recovery characteristics of the model
for the normal-spinning control configuration (elevator full up, ailerons
neutral, and rudder full with the spin) and for various other aileron-
elevator combinations including neutral and maximum settings of the
surfaces. Recovery was generally attempted by rapid reversal of the
rudder from full with to full against the spin. Tests were also per-
formed to evaluate the possible adverse effects on recovery of small
deviations from the normal control configuration for spinning. For these
tests, the elevator was set at two-thirds of its full-up deflection and
the ailerons were set at one-third of full deflection in the direction
conducive to slower recoveries (against the spin for the XF3D-1 model).
Recovery from this spin was attempted by rapidly reversing the rudder
from full with to two-thirds against the spin. This particular control
configuration and manipulation is referred to as the "criterion spin."

Turns for recovery are measured from the time the controls are moved
to the time the spin rotation ceases. The criterion for a satisfactory
recovery from a spin for the model has been adopted as 2 turns or less,
based primarily on the loss of altitude of the airplane during the
recovery and subsequent dive. Recovery characteristics of the model may
be considered satisfactory, however, if recovery attempted from the
criterion spin in the manner previously described requires only $2\frac{1}{4}$ turns.

PRECISION

A discussion of the general accuracies with which the weight and
mass distribution of spin-tunnel models are measured and with which the
spin results are presented, and a brief comparison of the results of
several model tests with full-scale spin results of the corresponding
airplanes, is contained in reference 1.

Because of the impracticability of exact ballasting of the model,
the measured moments of inertia varied from the true scaled-down values
by the following percents:

I_X . . . . 9 high
I_Y . . . . 2 high
I_Z . . . . 2 high

Control settings were made with an accuracy of $\pm1^\circ$.

TEST CONDITIONS

Mass characteristics and mass parameters for the normal gross-weight loading condition and other loading conditions possible on the XF3D-1 airplane, as well as for the loading tested on the XF3D-1 model, are listed in table II. The mass-distribution parameters for these loadings are plotted on figure 5. As discussed in reference 3, figure 5 can be used in predicting the relative effectiveness of the controls on the recovery characteristics of an airplane.

For the tests, the maximum control deflections used were:

Rudder, degrees . . . . 25 right, 25 left
Elevator, degrees . . . . 25 up, 15 down
Ailerons, degrees . . . . 20 up, 15 down

The corresponding intermediate control deflections used were:

Rudder 2/3 deflected, degrees . . . . $16\frac{2}{3}$

Elevator 2/3 up, degrees . . . . $16\frac{2}{3}$

Ailerons 1/3 deflected, degrees . . . . $6\frac{1}{3}$ up, 5 down

RESULTS AND DISCUSSION

Model Test Results

The test results for right and left spins were slightly different due, apparently, to a very slight asymmetry in the model. Although the results are presented for the direction which gave the slightly slower recoveries (arbitrarily presented as right spins), they are considered as representative of the airplane for spins in either direction.

Erect spins.— The results of the model erect spin tests are presented in table III for the clean condition and in table IV for the slow-down-brake-open condition. The results are generally similar to those obtained with the model used previously to simulate the XF3D-1 (reference 1), especially as regards the important parameter, turns required for recovery from the spins obtained at the various control configurations. Recovery characteristics were satisfactory when the model was in the clean condition and unsatisfactory when the slow-down brakes were open. The test results indicated that aileron-against settings.affected recoveries adversely, no recovery being obtained when the elevator was neutral or down if ailerons were full against the spin (stick left in a right spin). The results also indicated that elevator-down settings

affected recoveries adversely and therefore for optimum spin recovery
on the airplane the rudder should be reversed fully and rapidly, followed
approximately $\frac{1}{2}$-turn later by moving the stick forward of neutral while
maintaining it laterally neutral. Care should be exercised to avoid
entering a spin in the opposite direction following rudder reversal and
recovery. If a spin is inadvertently entered while the slow-down brakes
are open, the brakes should be retracted immediately and recovery attempted.

Inverted spins.— The inverted spin tests were very brief and the
results are not presented in tabular form. The XF3D-1 model would not
spin inverted when the ailerons and elevator were neutral, even when the
rudder was held full with the spin. Based on this result and on the
results of inverted spin tests of many models in the free-spinning tunnel,
it appears that satisfactory recoveries can be obtained from all inverted
spins that the XF3D-1 airplane may enter. To effect a recovery, the
rudder should be briskly and fully reversed to oppose the spin rotation
and the stick should be neutralized.

Landing Condition

Current Navy specifications require airplanes in the landing condi-
tion to demonstrate satisfactory recovery characteristics from only
1-turn spins. Full-scale flight experience indicates that a spinning
airplane is still in the incipient phase of the spin at the end of
1 turn and that recovery can generally be readily obtained. An analysis
of the results of spin tests of scale models of many airplanes indi-
cates, however, that if the spins of the XF3D-1 airplane in the landing
condition are allowed to develop fully, they may become flat and
recoveries may be slow. It is thus recommended that, in the landing
condition for this airplane, all fully developed spins be avoided and
that landing flaps be retracted and recovery attempted immediately upon
inadvertently entering a spin in the landing condition.

Mass Variations from the Normal Gross-Weight Loading

The mass parameters for the various loadings specified by the con-
tractor as possible for the XF3D-1 airplane are not appreciably different
from those of the normal gross-weight loading. Reference 4 indicates
that the tail-damping power factor and the mass characteristics of the
XF3D-1 airplane are such that the recovery characteristics should remain
satisfactory for any probable loading. The effects of control settings
and movements on the spins and recoveries should, in general, be the
same as those for the normal gross-weight loading.

Estimated Control Forces

The discussion so far has been based on control effectiveness alone without regard to the force required to move the controls. The controls of the airplane will have to be moved rapidly in order for the airplane recoveries to be comparable to the model test results. Based on the present test results and on the results of a recent investigation (reference 5) in which the force necessary to reverse the rudder of an airplane having a tail design somewhat similar to that of the XF3D-1 was measured during static tests of the model in attitudes simulating spinning conditions, it is estimated that the force necessary to reverse the rudder of the XF3D-1 airplane during a spin will be under 150 pounds, which is well within the physical capabilities of the pilot and which is in agreement with the preliminary estimate made in reference 1.

No estimate has been made of the stick force inasmuch as rudder reversal alone effected satisfactory recovery. It is felt that the force required to move the stick forward of neutral approximately 1/2 turn after rudder reversal, as recommended, will be within the capabilities of the pilot inasmuch as after the rudder reversal the airplane will nose down steeply and the elevator will therefore tend to float near neutral.

Estimated Spin-Recovery-Parachute Requirements

Based on the steady-spin parameters as given by the present test results and on a recent analysis of results of spin-recovery-parachute tests made on models in the free-spinning tunnel, it is estimated that the opening of a 10-foot-diameter flat-type parachute with a drag coefficient of 0.7 and attached to the tail of the airplane with a 30-foot towline will effect satisfactory spin recovery even if the rudder is not moved against the spin. A positive-ejection device should be used to throw the parachute pack clear of the tail and to assure rapid opening. Various practical tail-parachute installations are described in reference 6.

It is estimated that opening a 4.5-foot-diameter flat-type parachute with a drag coefficient of 0.7 and with the towline attached to the outer wing tip will also effect satisfactory spin recovery without movement of the rudder. The length of the towline should be such that the parachute when fully extended just clears the horizontal tail. The parachute pack and equipment should be mounted within the airplane structure and a positive-ejection device should be used to throw the pack clear and to assure rapid opening of the parachute.

The estimated spin-recovery-parachute requirements agree with the preliminary estimates made in reference 1.

Emergency Crew Escape

, Because the cockpit of the XF3D–1 airplane is located ahead of the leading edge of the wing, an additional hazard exists as regards emergency escape during a spin, inasmuch as the crew will have to clear the wing of the airplane as well as the tail. This hazard is particularly existent for those spins in which the rate of descent indicated for the airplane is greater than the terminal velocity of a man, as is the case for the XF3D–1, for the man will have to rise past the descending wing and may therefore be struck. In order to insure that the crew members can leave the airplane without being struck, an ejection system may be desirable. A recent analysis of results of tests in which model pilots were released for approximately 20 airplane models indicates that if no ejection system is provided and it becomes necessary to abandon the airplane, the crew should leave from the outboard side. There should be no obstruction in the cockpit between the pilot and the radar operator, so that they both can leave the airplane from the outboard side in a spin.

CONCLUSIONS

Based on the results of free–spinning–tunnel tests of a $\frac{1}{27}$–scale model of the XF3D–1 airplane, the following conclusions are made regarding the spin and recovery characteristics of the airplane; these conclusions are similar to those presented in reference 1.

1. For any of the loadings specified by the contractor as possible for the airplane, the spin obtained for the normal–spinning control configuration for the clean condition will be steep and the recoveries will be fast.

2. For fast recoveries from erect spins, the stick should be held full back and laterally neutral, and the rudder should be fully and rapidly reversed; approximately 1/2 turn after rudder reversal, the stick should be briskly moved forward of neutral and maintained laterally neutral. Aileron–against settings should be avoided if possible. For satisfactory recoveries from inverted spins, the rudder should be reversed and the stick neutralized.

3. Recoveries from spins with the slow–down brakes open will be slow and recoveries from fully developed spins in the landing condition may be slow. Slow–down brakes or landing flaps should be retracted immediately upon entering a spin.

4. The force necessary to reverse the rudder during a spin will be within the physical capabilities of the pilot.

5. A 10-foot-diameter tail parachute or a 4.5-foot-diameter parachute on the outer wing tip (flat-type parachute with drag coefficient of 0.7) will be satisfactory for emergency recovery from demonstration spins.

6. If it is necessary for the crew to abandon the airplane during a spin, they should attempt to escape from the outboard side of the cockpit.

Langley Memorial Aeronautical Laboratory
    National Advisory Committee for Aeronautics
        Langley Field, Va.

Stanley H. Scher
Aeronautical Engineer

Approved: Thomas A. Harris
    Thomas A. Harris
Chief of Stability Research Division

CMH

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SUPPLEMENTARY REFERENCES

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TABLE I.— DIMENSIONAL CHARACTERISTICS OF THE XF3D—1 AIRPLANE

[Dimensions are full scale]

Over—all length, ft 45.38

Wing:
    Span, ft 50
    Area, sq ft 400
    Section, root . . . . NACA 1412—64
    Section, tip . . . . NACA 1412—64
    Root (reference) chord incidence, deg 5
    Tip—chord incidence, deg 3
    Aspect ratio 6.25
    Sweepback of leading edge of projected wing, deg 5.35
    Dihedral leading—edge chord line, deg 3.0
    Length of mean aerodynamic chord, in. 99.5

Ailerons:
    Chord (rearward of hinge line), percent of wing chord 22
    Area (rearward of hinge line), percent of wing area 8.7
    Span, percent of wing span 45.0

Horizontal tail surfaces:
    Incidence from fuselage
       reference line, deg . . . . Leading edge 3.5 up to 0
    Total area, sq ft 92.56
    Span, ft 20.5
    Elevator area (rearward of hinge line), sq ft 24.74
    Distance from center of gravity to
       elevator hinge line, ft 24.40

Vertical tail surfaces:
    Total area, sq ft 49.7
    Rudder area (rearward of hinge line), sq ft 11.46
    Distance from center of gravity to rudder hinge line, ft . . . 22.27

Tail—damping power factor (computed by method
    described in reference 4) 0.001060

Tail—damping ratio (computed by method
    described in reference 4) 0.050700

Unshielded rudder volume coefficient (computed
    by method described in reference 4) 0.021000

TABLE II.— MASS CHARACTERISTICS AND MASS PARAMETERS FOR VARIOUS LOADINGS SPECIFIED AS POSSIBLE ON THE

XF3D-1 AIRPLANE AND FOR THE LOADING TESTED ON THE $\frac{1}{27}$—SCALE FREE-SPINNING MODEL

No.	Loading	Weight (lb)	μ sea level	μ at 16,000 ft	Center-of-gravity location		Moments of inertia about the center of gravity			Mass parameters		
					$x/\bar{c}$	$z/\bar{c}$	I_X (slug-ft^2)	I_Y (slug-ft^2)	I_Z (slug-ft^2)	$\dfrac{I_X - I_Y}{mb^2}$	$\dfrac{I_Y - I_Z}{mb^2}$	$\dfrac{I_Z - I_X}{mb^2}$
							Airplane values					
1	Normal gross weight	21,500	14.0	23.0	0.231	-0.031	16,602	40,651	53,807	-144×10^{-4}	-79×10^{-4}	223×10^{-4}
2	Design flight gross weight; nose heavy	18,100	11.8	19.4	.180	.01	15,918	40,724	54,003	-177	-94	271
3	Design landing gross weight; tail heavy (gear down)	16,200	10.6	17.4	.295	.031	15,467	36,876	49,136	-170	-98	268
							Model values converted to full-scale values					
1	Normal gross weight	21,349	13.9	22.9	0.231	-0.030	17,433	40,958	54,671	-142×10^{-4}	$-82. \times 10^{-4}$	225×10^{-4}

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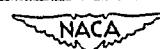
TABLE III.— SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{27}$—SCALE MODEL OF THE

DOUGLAS XF3D-1 AIRPLANE IN THE CLEAN CONDITION

[Normal gross-weight loading (point 1 on table II and fig. 5); recovery by rapid full
rudder reversal except as noted; recovery attempted from, and steady-spin data
presented for, rudder-full-with spins; right erect spins; model values are given
in terms of corresponding full-scale values]

Ailerons	Against				Neutral			With		
	Full			1/3						
Elevator	Up (a,b)	Neutral	Down	2/3 up	Up (a,c)	Neutral	Down	Up (b,c)	Neutral (c)	Down (c)
α, deg	26	36	38	28	-----	25	29	-----	-------	----
ϕ, deg	7U	8U	8U	5U	-----	2U	2U	-----	-------	----
Ω, rps	0.26	0.34	0.34	0.26	-----	0.41	0.45	-----	-------	----
V, fps	314	292	274	356	>372	333	295	>404	>404	>404
Turns for recovery	$\frac{1}{2}$ 1	∞	∞	$^{d}\frac{3}{4}$ $^{d}1$ $^{d,e}1$	$^{f}\frac{1}{4}$ $^{f}\frac{1}{4}$	1 $1\frac{1}{4}$	$2\frac{1}{2}$ $2\frac{1}{2}$	$^{f}\frac{1}{4}$ $^{f}\frac{1}{4}$	$^{f}\frac{3}{4}$ $^{f}1$	$^{f,g}\frac{1}{4}$ $^{f,g}\frac{1}{4}$

[a] Wandering spin.
[b] Model made periodic whipping motion.
[c] Steep spin.
[d] Recovery attempted by reversing rudder from full with to two-thirds against the spin.
[e] Model tended to turn in opposite direction after recovery.
[f] Recovery attempted before model reached its final steep attitude.
[g] Model went into inverted spin upon recovery.

U and D signify inner wing up or down, respectively, in developed spin.
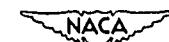
TABLE IV.— SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{27}$—SCALE MODEL OF THE

DOUGLAS XF3D-1 AIRPLANE WITH SLOW-DOWN BRAKES FULLY OPENED

[Normal gross-weight loading (point 1 on table II and fig. 5); recovery by rapid full
rudder reversal except as noted; recovery attempted from, and steady-spin data
presented for, rudder-full-with spins; right erect spins; model values are given
in terms of corresponding full-scale values]

Ailerons	Against			Neutral			With	
	Full		1/3					
Elevator	Neutral (a)	Down (a)	2/3 up	Up (b)	Neutral	Down	Neutral (c)	Down (c)
α, deg	37 / 60	34 / 64	30	35	35	36	-------	----
ϕ, deg	20U / 15D	3U / 19D	4U	1D	4U	4U	-------	----
Ω, rps	0.32	0.33	0.23	0.21	0.34	0.37	-------	----
V, fps	259	248	288	310	288	266	>356	>404
Turns for recovery	∞	∞	d ∞	$\frac{1}{2}$ / $1\frac{1}{2}$	∞	∞	-------	----

a Spin is oscillatory in yaw and pitch.
b Wandering spin.
c Steep spin.
d Recovery attempted by reversing rudder from full-with to two-thirds against the spin.

U and D signify inner wing up or down, respectively, in developed spin.
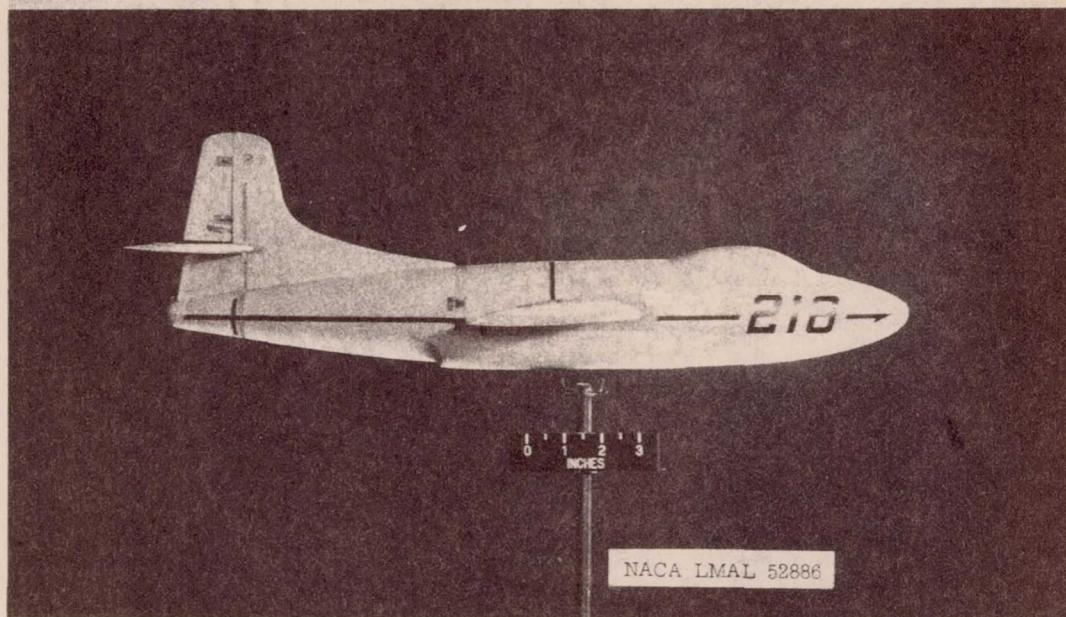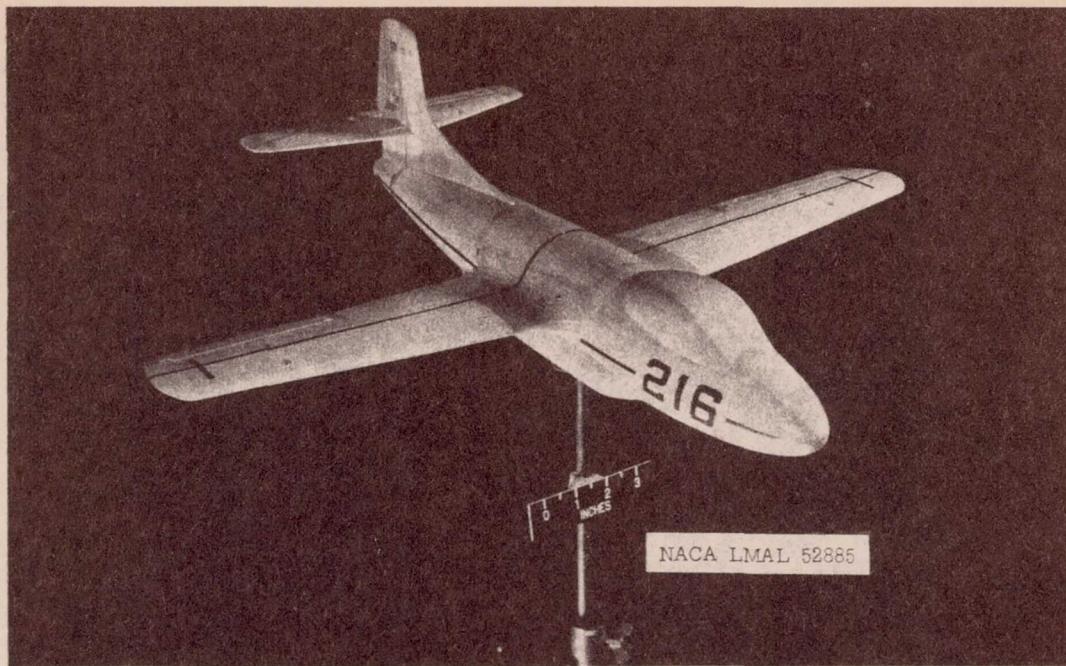
Figure 1.- Photographs of the $\frac{1}{27}$-scale model of the XF3D-1 airplane tested in the free-spinning tunnel.   Model is shown in the clean condition.
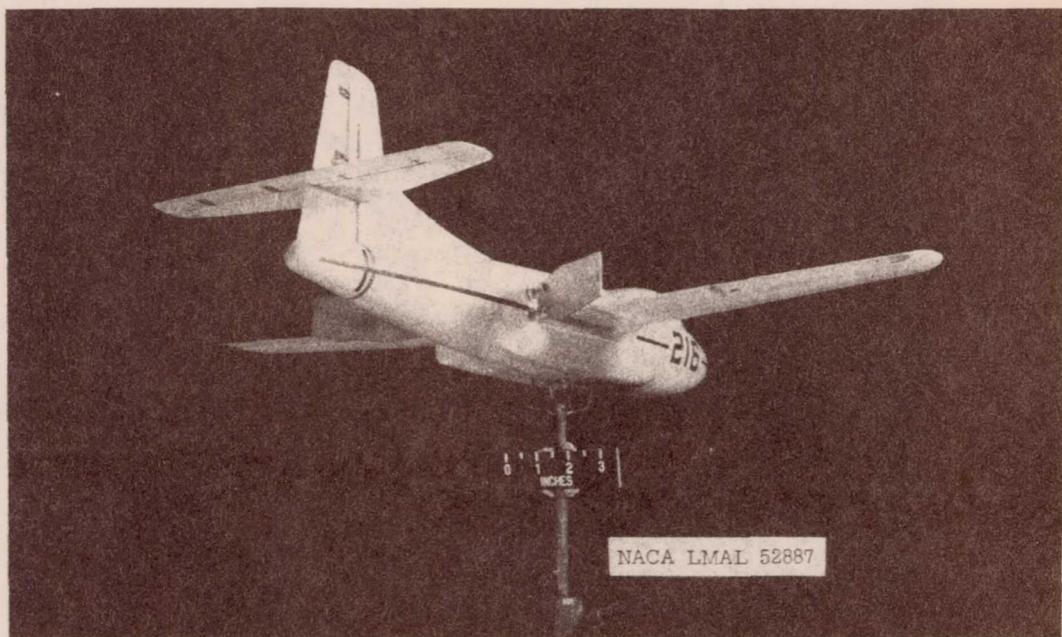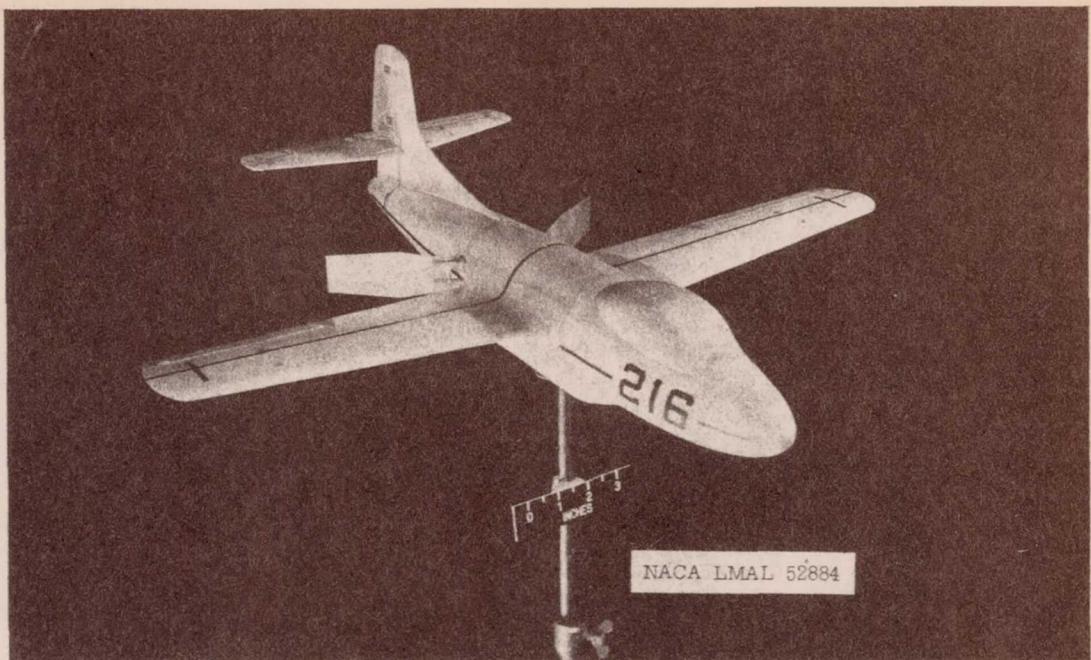
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Figure 2.- Photographs of the $\frac{1}{27}$-scale model of the XF3D-1 airplane tested in the free-spinning tunnel. Model is shown with the slow-down brakes in the fully open position.

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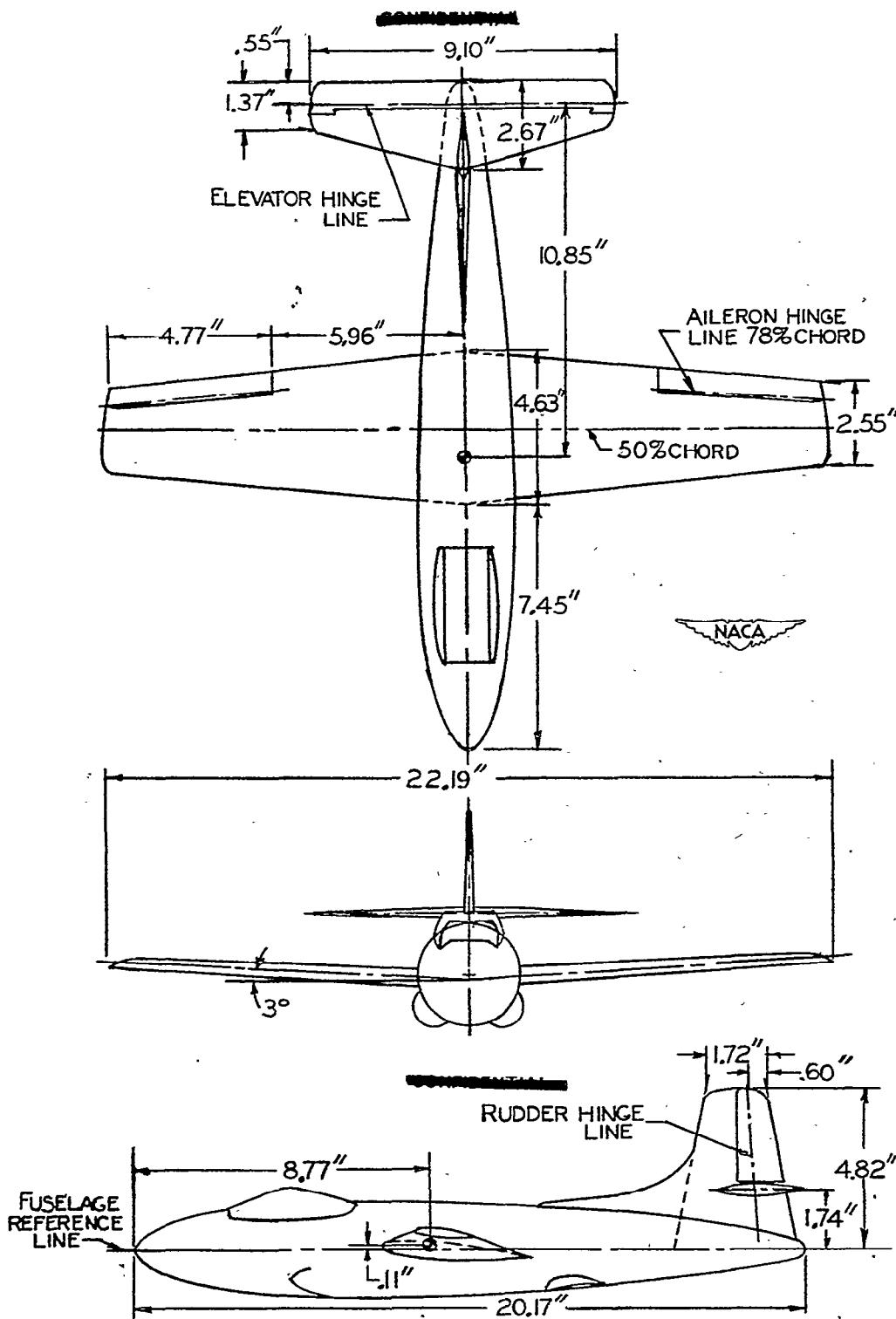
FIGURE 3.— THREE-VIEW DRAWING OF THE $\frac{1}{27}$–SCALE MODEL OF THE XF3D-1 AIRPLANE TESTED IN THE FREE-SPINNING TUNNEL. CENTER OF GRAVITY IS SHOWN FOR THE NORMAL GROSS WEIGHT LOADING. DIMENSIONS ARE MODEL VALUES.

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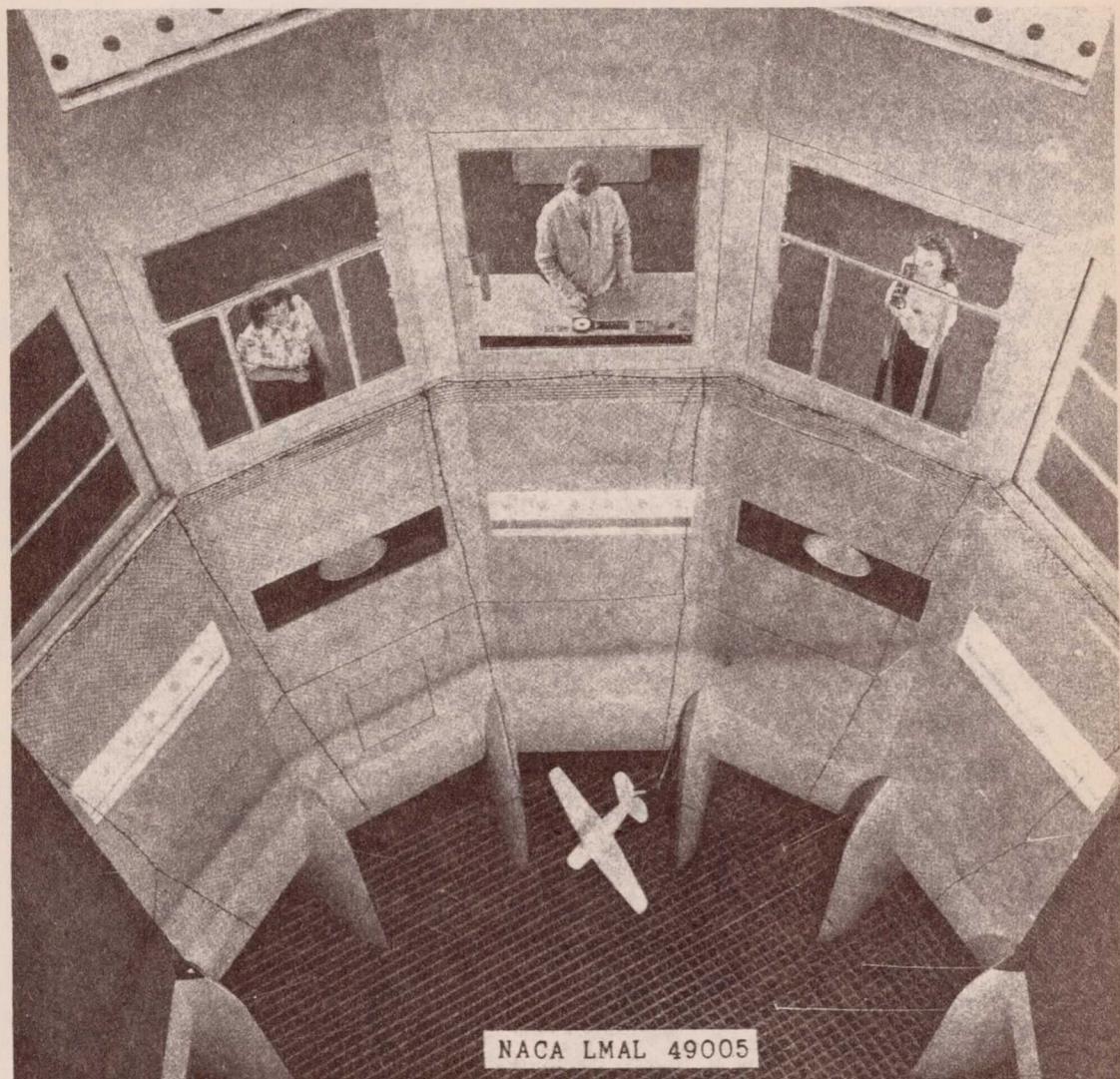
Figure 4.- Photograph showing the test section of the 20-foot free-spinning tunnel and a model spinning in the tunnel.

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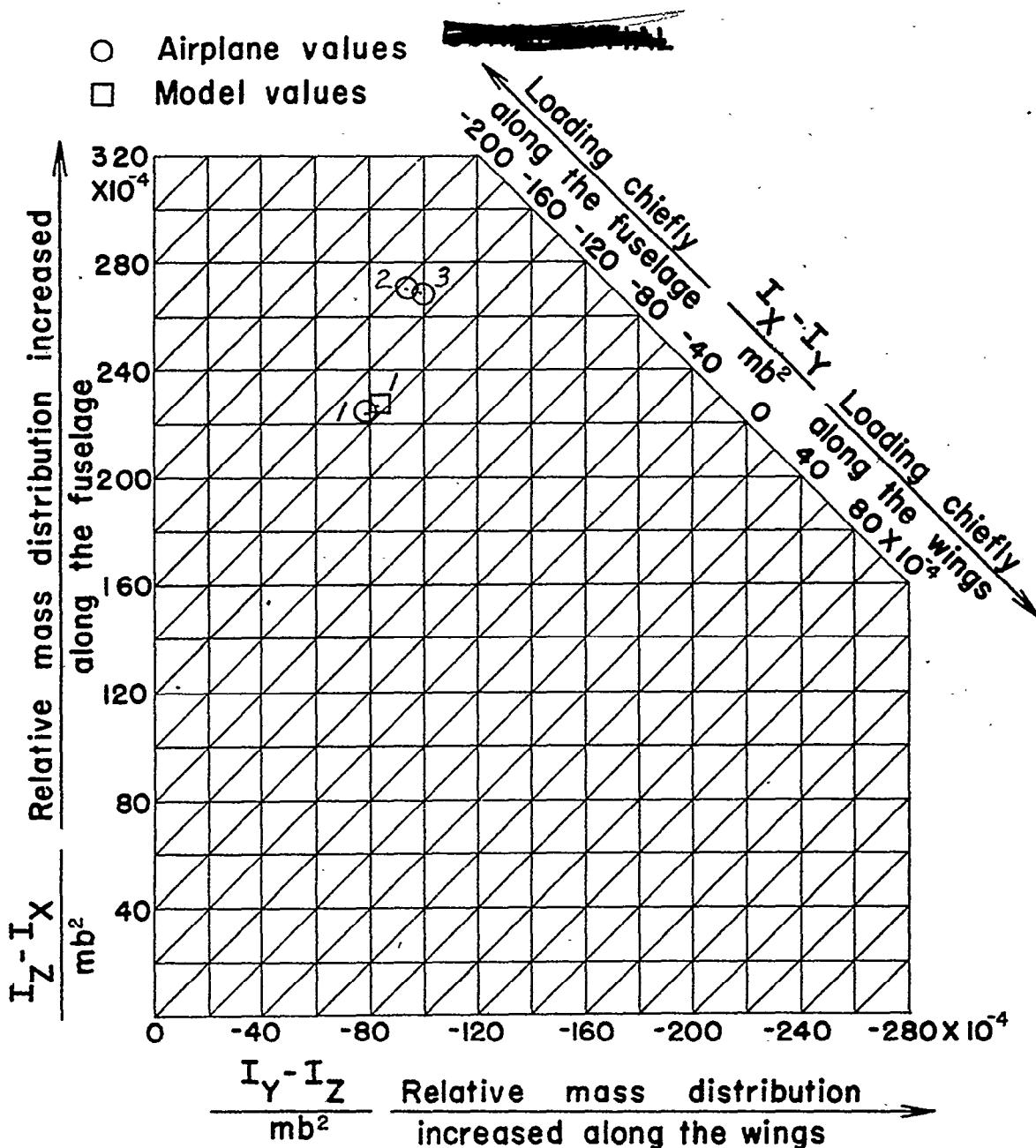
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Figure 5.– Inertia parameters for loadings possible on the Douglas XF3D-1 airplane and for the loading used on the XF3D-1 model (points are for loadings listed on table II).